Before the
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

In the matter of	)	
Mitigation of Orbital Debris	)	IB Docket No. 02-54
	)	

To: The Commission

REPLY COMMENTS of
Victor J. Slabinski, PhD (physics)

who has over 26 years experience in analyzing the orbital mechanics and control of communications satellites operating near geostationary earth orbit, including their long term motion after placement in a disposal (graveyard) orbit.

SUMMARY

1) A look at part of the historical record shows that operator self-interest does not routinely result in successful end-of-life orbit raising; regulation and additional incentives appear to be required.

2) Suggestions are offered on the practical use of the IADC formula for the minimum required orbit raising above GEO (Geostationary Earth Orbit) altitude at end-of-life.

3) A possible inadequacy in the IADC formula is discussed which may require revision to the formula.

REBUTTAL TO COMMENTS THAT DEBRIS MITIGATION REGULATION IS NOT NECESSARY FOR GEO SATELLITE OPERATORS

1) The Satellite Industry Association argues that GEO "satellite operators have a commercial interest in relocating their spacecraft to safe [disposal] orbits at end-of-life" [Ref. 1]. They argue that "U.S.-licensed operators ... have historically removed satellites at the end-of-life to storage orbits, which do not interfere with ... the permanent orbit of existing or follow-on satellites" [Ref. 2], and thereby conclude that debris mitigation regulation is not necessary.

For this assertion to be convincing, the Association needs to document the historic orbit-raising success rate of its members. How often has voluntary orbit raising succeeded in placing the station in a disposal orbit with perigee above the planned target altitude?

The statistics readily available to this respondent indicate that the historic success rate has not been high:

a) An AIAA report [Ref. 3] states that "In 2000, only two of nine GEO satellites that ended their lives were reorbited to an effective disposal orbit".

b) In 1982, the INTELSAT Board of Governors resolved that at end of life, their Intelsat IV and IVA series of communications satellites would be reorbited to at least 150 km above GEO. (This disposal altitude was felt to be adequate at that time.) The seven Intelsat IV and five Intelsat IVA spacecraft reached end of life between 1983 and 1989. Of these 12 spacecraft, only six (one-half of the total) were successfully reorbited above the target altitude; the remaining six were left with disposal orbit perigees distributed between 5 and 115 km above GEO, that is, well below the 150 km target altitude. These low perigee heights are the result of early propellant depletion during the orbit raising maneuvers.

The above statistics indicate that operator self-interest does not routinely result in successful end-of-life orbit raising. Regulation and additional incentives appear to be required. For example, space-station operators could be required to post a large performance bond (of at least $1,000,000 per spacecraft) before launch, to be refunded after space-station removal to the required orbit separation from GEO altitude. My previously filed comment [Ref. 4] for this docket gives the practical reasons for a performance bond.

PRACTICAL PROBLEMS WITH THE IADC FORMULA FOR MINIMUM DISPOSAL HEIGHT ABOVE GEO ALTITUDE

2)   The Commission proposes that at end-of-life, space stations in GEO should be removed to disposal orbits with an initial perigee above a stated minimum height above GEO altitude. I applaud the Commission proposal to adopt the Inter-Agency Space Debris Coordination Committee ("IADC") formula (NPRM sec.54, p.24 and Appendix B, p.37) which makes the minimum height depend on the effective area/mass ratio of the spacecraft. This formula allows for the periodic variations in perigee height of the disposal orbit due to solar radiation "pressure" perturbations, variations which are proportional to the area/mass ratio.

However, I agree with the comments from the Satellite Industry Association [Ref. 2] that the Commission should clarify the cross-sectional "Area" of the spacecraft to use in the IADC formula. What value should be used if the cross-section varies with the Sun direction relative to spacecraft geometric axes, and how is the "Area" value best determined?

I offer some suggestions on this matter to the Commission in what follows. I use the term "effective area" which corresponds to the product (CR*A) in the IADC formula since only this product is important and only this product can be obtained from observed changes to spacecraft orbits.

a)   The same solar radiation "pressure" which affects the perigee height of disposal orbits also produces observable perturbations to the orbits of operational space-stations. In order to allow for these perturbations as part of routine longitude stationkeeping, operators determine the "effective area/mass" ratio as part of their orbit determination process. From the known spacecraft mass, a reliable "effective area" can be computed for use with the spacecraft "dry mass" [mass after propellant depletion] in the IADC formula.

In summary, the "effective area" to use in the IADC formula should be based on orbit-determination solutions. The value so obtained would account for the actual on-orbit deployments of antennas, solar arrays, etc.

b) The sunlight-reflection properties of the spacecraft surface material change with time due to exposure to the harsh space environment; this may change the "effective area" value. For this reason, the "effective area" to use in the IADC formula should be based on orbit observations during the last several years before end-of-life disposal.

c) Because communications satellites generally have odd, irregular shapes, it is difficult to compute an accurate "effective area" from the geometric dimensions and measured sunlight-reflection properties of the spacecraft surfaces. Analysts who attempt such calculations find that their computed values have errors of order 20 percent compared to the value based on orbit determinations.

For this reason,"effective area" values based on orbit determinations should be preferred to calculated values. The resulting difference in computed minimum orbit-raising height could be of order 20 km for a space-station with a very large area/mass ratio (of order 0.1 square meter per kilogram).

d) Routine orbit determination for GEO space-stations shows that the "effective area" generally varies during the year as the Sun's direction from the orbit plane changes. This is due to a change in spacecraft cross-section as seen from the Sun. The variation is fairly repeatable from year to year. The question arises that if the "effective area" so varies, what value should be used in the IADC formula?

e) A conservative approach might be to just use the largest observed value in the formula and thereby maximize the computed minimum-required-height for orbit raising. However, the "effective area" variation can lead to some unexpected large orbit changes, as explained in the next section.

A CAUTION ON THE USE OF THE IADC FORMULA

3) The mathematical derivation of the IADC formula has never been formally published in a public document or technical journal, so the assumptions made and the resulting derivation is not available for verification by outside astrodynamics analysts. I have been able to mathematically derive the formula on the simplifying assumption (frequently used in orbit analyses) that the disposed spacecraft may be approximated by an absorbing sphere, that is, that its "effective area" does not vary with Sun direction. The

resulting analysis shows that the perigee height of an initially circular disposal orbit undergoes an annual oscillation due to solar radiation "pressure"; solar pressure makes no net change to perigee height over the year.

But if I allow for a variation in "effective area" with Sun direction from the orbit plane, with some reasonable asymmetry between the Sun appearing "north" and "south" of the orbit plane, I find that solar pressure not only gives an annual oscillation, but there is also a net change in perigee height over the year. This result is at variance with the IADC theory. Over a number of years, the perigee height of an initially circular disposal orbit can be lowered by more that twice the IADC limit.

This is a new result which requires study by the orbit experts. Once I have documented my results, I am willing to share them with the Commission and make them available for technical journal publication.

In the meantime, the Commission should leave open the possibility that the IADC formula may need revision a year from now to give larger values.

REFERENCES

"Comments" are comments filed for this docket and posted on the FCC Electronic Comment Filing System.

1. DalBello, Richard, "Comments of the Satellite Industry Association" (July 17, 2002), p.ii and p.2.

2. Ibid., p.14.

3. American Institute of Aeronautics and Astronautics, "6th International Space Cooperation Workshop Report" (March 2001), p.12. (Copy available at www.aiaa.org and in the FCC docket file.)

4. Slabinski, Victor J., "Comment on Disposal of Retired GEO Communications Satellites" (July 17, 2002).

Respectfully submitted,

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